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NGC922 - A new drop-through ring galaxy. *

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ABSTRACT

We have found the peculiar galaxy NGC922 to be a new drop-through ring galaxy using multi-wavelength (UV-radio) imaging and spectroscopic observations. Its 'C'-shaped morphology and tidal plume indicate a recent strong interaction with its companion which was identified with these observations. Using numerical simulations we demonstrate that the main properties of the system can be generated by a high-speed off-axis drop-through collision of a small galaxy with a larger disk system, thus making NGC922 one of the nearest known collisional ring galaxies. While these systems are rare in the local Universe, recent deep HST images suggest they were more common in the early Universe.

Key words: galaxies: individual - classification - ring galaxy: structure

1 INTRODUCTION

Interests in ring galaxies as examples of galaxy collisions dates back to early simulations of the famous Cartwheel Galaxy (Lynds & Toomre 1976), which was modelled by a small galaxy passing through a larger one. This interaction is thought to spread out stellar populations, induce star formation and thicken the disk of the larger galaxy. Here we present observations of the peculiar galaxy NGC922 which Block et al. (2001) describe as a dust-obscured grand design spiral. Here we argue that it is in fact a particularly nearby example of this phenomena and we identify its perturber.

We find striking resemblances between this galaxy and several high-redshift galaxies categorised as *clump cluster* galaxies by Elmegreen et al. (2005). Since both galaxy density and the dispersion about the Hubble flow increase with redshift, the probability of interactions between galaxies should also increase. Hence, ring galaxies should be more common in the early Universe.

* Based on observations with the NASA Galaxy Evolution Explorer. GALEX is operated for NASA by the California Institute of Technology under NASA contract NAS5-98034.

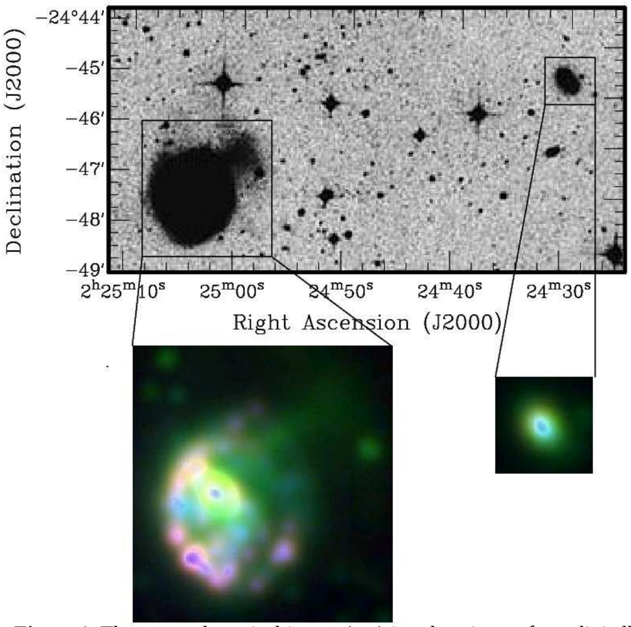

Figure 1. The greyscale optical image (top) is a deep image from digitally-stacked plates of NGC922 (bottom-left) and S2 (top-right). The height of the greyscale image is ∼4′. The enlarged images are SINGG-SUNGG composite images of NGC922 and S2 where red represents Hα, green represents R-band and blue represents FUV. A diffuse plume of stars on the north-western side of NGC922 can be seen in the R-band to be extending towards the companion.

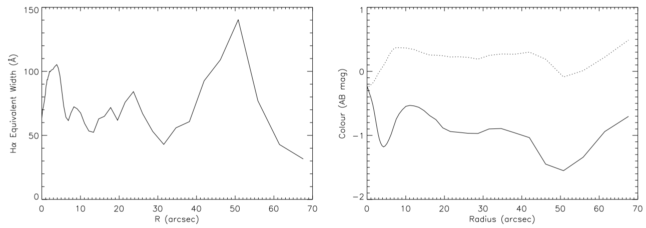

Figure 2. The Hα equivalent width (radial) profile of NGC922 is shown on the left and radial colour profiles of NGC922 are shown on the right where the FUV-NUV and FUV-R colour profiles are represented by the dotted and solid lines respectively .

Our intent in this discovery paper, is to present the available observational properties of the system, identify the companion and demonstrate that the system can be accounted for by an off-axis collision model. We describe our multiwavelength observations in Section 2. Section 3 presents our numerical simulations, which reproduces NGC922's ring morphology from simple dynamical modelling.

2 OBSERVATIONS

The Survey for Ionization in Neutral Gas Galaxies (SINGG Meurer et al. 2006) and its sister survey, the Survey of Ultraviolet emission of Neutral Gas Galaxies (SUNGG) are surveys in the Hα and ultraviolet (UV) of an HI-selected sample of galaxies from the HI Parkes All Sky Survey (HIPASS; Meyer et al. (2004), Koribalski et al. (2004)). SINGG consists of optical R-band and Hα images obtained primarily from the 1.5m telescope at Cerro Tololo Inter-American Observatory (CTIO), Chile. The Galaxy Evolution Explorer (GALEX) satellite telescope is used to obtain the far-ultraviolet (FUV) 1515Å images and near-ultraviolet (NUV) 2273Å images for SUNGG.

In addition, observations from the 6-degree Field Galaxy Survey, 6dFGS, (Jones et al. 2004) and the Two Micron All Sky Survey, 2MASS, (Jarrett et al. 2000) were also used.

2.1 Multi-wavelength morphology and luminosity

Two Hα sources, HIPASSJ0224-24:S1 (NGC922) and HIPASSJ0224-24:S2 (2MASXJ02243002-2444441) were identified with the SINGG data (Meurer et al. 2006). For convenience, we refer to the first source as NGC922 and its companion as S2 in this paper. A deep greyscale optical image of the NGC922 field created from UK Schmidt plates, courtesy David Malin[1] is as shown in Fig 1 where NGC922 is located in the south-east corner and its companion is projected 8.2′(102 kpc) towards the north-west. The enlarged images of NGC922 and S2 are colour composite images where red represents Hα, green represents R-band and blue represents FUV. The distance of 43 Mpc to the NGC922/S2 system was derived from the HI radial velocity, using the Mould et al. (2000) distance model and adopting a Hubble constant $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (Meurer et al. 2006). Young star-forming regions in NGC922's ring are revealed with the Hα and FUV observations. As shown clearly in the deep optical image from Figure 1, a spray of stars (only visible in R-band in the bottom colour image) from NGC922 can be seen to be extending towards S2.

The Hα equivalent width (EW) profile and the radial colour profiles of NGC922 are shown in Figure 2. All the profiles were generated with the same isophotal parameters using the task ELLIPSE in IRAF[2]. Concentric ellipses were fitted in each image centred on the location of the NUV brightness peak. The surface brightness radial profile was then measured as a function of semi-major distance from that location. The position angle of NGC922 is 51°. It can be seen from the Hα EW profile that the brightness peak in Hα (at 5″) is slightly displaced from the NUV brightness peak. The central colour dip corresponds to the central peaks in FUV and NUV. The two main peaks in the Hα EW profile correspond to the core of the galaxy (R $\sim$ 5″) and the ring (R $\sim$ 50″). Likewise, the FUV-NUV colour profile shows minima at these radii. Hence, star formation is enhanced in the core and especially the ring. This indicates that star formation is a propogating, in NGC922. We also find the inner regions of NGC922 to be slightly redder, presumabley older, than the outer regions as shown by the FUV-R profile in Figure 2, and in agreement with ring galaxy model predictions (e.g. Hernquist & Weil 1993)

The optical spectra and NIR images (JHK bands) of NGC922 and S2 were obtained from the 6dF Galaxy Redshift Survey (Jones et al. 2004) and the 2MASS Extended Source Catalog (Jarrett et al. 2000), respectively. Radial velocities of NGC922 and S2 were measured from the spectra and are as listed in Table 1. The fibre diameter of the 6dF instrument is 6.7″which translates to an aperture size of 1.4 kpc for NGC922.

Both the NUV and FUV magnitudes were corrected for fore-

[1] http://www.aao.gov.au/images/deep_html/n0922_d.html
[2] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Table 1. Observed properties of NGC922 and S2.

Properties	NGC922	S2
RA [J2000]	02:25:04.4	02:24:30.0
Dec [J2000]	-24:47:17	-24:44:44
$v_{\rm h}$ [km s^{-1}]	3077	3162
$E(B-V)_{\rm G}$ [mag]	0.019	0.018
$E(B-V)_i$ [mag]	0.21	0.23
$(M_{\rm R})_0$ [ABmag]	-21.59	-18.45
$(FUV-NUV)_0$ [ABmag]	-0.09	-0.08
$(NUV-R)_0$ [ABmag]	1.52	1.32
$(R-J)_0$ [ABmag]	0.90	0.75
$(J-H)_0$ [ABmag]	0.54	0.44
$(H-K)_0$ [ABmag]	0.16	0.58
$f_0(H\alpha)$ [10^{-12} ergs cm^{-2}s^{-1}]	4.65 ± 0.18	0.145 ± 0.017
$EW_{H\alpha}$ ($\AA$)	77±3	43±5

ground Galactic reddening using the relationships of Seibert et al. (2005) based on the dust reddening maps of Schlegel et al. (1998). The FUV attenuation ($\rm A_{FUV}$) due to internal extinction was also calculated using the $FUV - NUV$ relations by Seibert et al. (2005). A more direct method of estimating $\rm A_{FUV}$, using the ratio of the IRAS far infrared (FIR) flux with the FUV flux (Meurer et al. 1999), was also calculated for NGC922. Both $\rm A_{FUV}$ values are comparable and equal 1.09 and 0.95 using the Seibert et al. (2005) and the Meurer et al. (1999) methods respectively. This derived $\rm A_{FUV}$ is lower than most of the attenuations found in the local UV bright starburst galaxies (Meurer et al. 1999). IRAS data is not available for S2 and so the Seibert et al. (2005) method is used for both NGC922 and S2.

The intrinsic fluxes ($f_0(\lambda)$), free from internal dust extinction, of NGC922 and S2 were calculated from the observed fluxes ($f(\lambda)$) for the NUV, R, J, H and K measurements via,

$$f_0(\lambda) = f(\lambda) 10^{0.4E(B-V)_i k^e(\lambda)} \qquad (1)$$

where $E(B-V)_i$ is the reddening excess intrinsic to the galaxy which can be estimated using the relationships found in Calzetti et al. (1994). The extinction relations for the stellar continuum ($k^e(\lambda)$) were calculated from the correlations determined by Calzetti et al. (2000). The intrinsic Hα fluxes were derived from the intrinsic R-band attenuation ($A_{\rm R,i}$) from the adopted relation $A_{\rm H\alpha,i} \approx 2A_{\rm R,i}$ (Calzetti et al. 1994). A summary of foreground and internal extinction values in addition to the observed properties of NGC922 and S2 from SINGG, SUNGG and 2MASS can be found in Table 1.

2.2 SFR, metallicity and mass

The SFR was calculated: i) using the Hα luminosity, $L_{\rm H\alpha}$[erg s^{-1}] (Kennicutt et al. 1994):

$$SFR_{H\alpha} = \frac{L_{\rm H\alpha}}{1.26 \times 10^{41}} \qquad (2)$$

and ii) using the FUV luminosity, $L_{\rm FUV}$ [erg s^{-1} Hz^{-1}] (Kennicutt 1998):

$$SFR_{FUV} = 1.4 \times 10^{-28} L_{\rm FUV} \qquad (3)$$

The SFR calculated from method (i) for NGC922 and S2 are 8.2 M$_\odot$ year^{-1} and 0.26 M$_\odot$ year^{-1}, respectively. Similarly, the SFR calculated using the FUV luminosities for NGC922 and S2 are 7.0 M$_\odot$ year^{-1} and 0.47 M$_\odot$ year^{-1}, respectively.

Table 2. Derived properties of NGC922 and S2.

Properties	NGC922	S2
$log(O/H)+12$	8.6-9.0	8.3-8.6
Z [Z$_\odot$]	0.5-1.0	0.3-0.5
$SFR_{H\alpha}$ [M$_\odot$ year^{-1}]	8.20 ±0.32	0.26 ±0.03
SFR_{FUV} [M$_\odot$ year^{-1}]	7.04±0.02	0.47 ±0.02
$M_\star$ [M$_\odot$]	5.47 $\times 10^9$	2.82 $\times$ 10^8
$M_{\rm dyn}$ [M$_\odot$]	6.65×10^{10}	–
$M_{\rm HI}$ [M$_\odot$]	1.2×10^{10}	–

The oxygen abundance (log(O/H)+12) and metallicity (Z) can be approximated using the integrated flux ratios of various emission lines from the 6dF optical spectra. Within the wavelength range of the 6dF spectra, it is possible to use the integrated flux ratios of of the [NII] and [SII] emission lines as well as the flux ratios of [NII] and $H\alpha$ (Kewley & Dopita 2002). The [NII]/[SII] = 1.12, 0.538 was measured for NGC922 and S2, respectively. Assuming the average ionisation parameter, $q = 2 \times 10^7$ cm s^{-1}, log(O/H)+12 equals 9.0 and 8.6 respectively for NGC922 and S2. These values indicate that the metallicity of NGC922 is ∼1.0 $Z_\odot$ and the metallicity of S2 is ∼0.5 $Z_\odot$. Using the flux ratios of [NII]/Hα, log(O/H)+12 equals 8.6 (∼0.5 $Z_\odot$) and 8.3 (∼0.3 $Z_\odot$) for NGC922 and S2 respectively. Using the luminosity-metallicity relation found by Lamareille et al. (2004) for R-band luminosities in the local Universe, log(O/H)+12 equals 9.1 and 8.3 for NGC922 and S2 respectively. Both galaxies agree with the luminosity-metallicity relation.

The stellar mass ($M_\star$) of NGC922 can be estimated using the K band fluxes and the calibrations of Bell et al. (2003). Using this method, $M_\star$ is approximately 5.47×10^9 M$_\odot$ for NGC922, while S2 has an order of magnitude less stars: $M_\star = 2.82 \times 10^8$ M$_\odot$, assuming it is a typical S0-Sa galaxy (as judged by its morphology) with B-V colour of 0.8 (Sparke & Gallagher 2000). Assuming that the HI line profile is dominated by NGC922 and its width gives the rotational velocity at the optical radius, one can estimate the enclosed dynamical mass using

$$M_{dyn}(R) = \frac{V_R^2 R}{G} \qquad (4)$$

where $V_R \approx 146$ km s^{-1} is the inclination corrected rotational velocity, the maximum radius of the R-band surface brightness profile $R = 13.4$ kpc and G is the gravitational constant. This yields a dynamical mass of 6.65×10^{10} M$_\odot$ within 13.4 kpc. The HI mass ($M_{\rm HI}$) of NGC922 was measured to be 1.2×10^{10} M$_\odot$ by HIPASS. We see that 8% and 20% of the dynamical mass of NGC922 are due to the stellar and HI mass respectively. It is probable from these calculations that most of the mass can be attributed to dark matter. The system is not in virial equilibrium and is expanding. This will mean that the total mass is probably an overestimation. As yet, the only HI observation of NGC922 does not have enough spatial resolution to trace the neutral gas morphology of the system, hence, higher resolution HI mapping of this system is needed to check if gaseous tails exist, such as the ones found in the Cartwheel Galaxy (Higdon 1996). This would further verify our interacting companion. Table 2 summarizes the derived properties of both NGC922 and S2.

3 ANALYSIS

Block et al. (2001) argue that the peculiar properties of NGC922 mark it as a dust-obscured grand design spiral galaxy in the process of assembly, and hence it largely results from secular (interaction free) evolution. Secular processes are indeed important in the present epoch (Kormendy & Kennicutt 2004) and can even produce ring like structures. However in those cases the ring typically accompanies a strong bar producing a θ morphology, quite different from what is observed in NGC922. While some aspects of NGC922's morphology may have a secular origin, the observed evidence for a strong interaction is very compelling.

We propose that the outstanding properties of NGC922 are likely to be the result of a high-speed, off-centre collision between a gas-rich disk galaxy and a dwarf companion for the following reasons: 1) The stellar plume observed in NGC922 extending towards S2 is most likely to be caused by an external mechanism such as the tidal interaction between NGC922 and its companion galaxy. 2) Numerous simulations (e.g. Hernquist & Weil 1993) have shown that ring structures can be formed from outwardly-propagating waves. 3) From our observations of the flocculent region in between the centre and the ring of NGC922, the 'arms' of the inner spiral observed by Block et al. (2001) can be described as 'spoke'-like structures analogous to those observed in the Cartwheel galaxy. 4) The high SFR and EW of NGC922 and S2, coupled with the low gas cycling time of the system indicates a recent starburst. We are aware that this reason alone does not necessarily rule out a secular origin for the global properties of NGC922 since starbursts have been observed in systems with no obvious companions (e.g. Meurer et al. 1996). Similarly, simulations show that if a bar or disk can be displaced from the centre of mass in a galaxy, lopsided arms or a single arm can result in a morphology similar to NGC922's partial ring, although an external pertubation still may be needed to excite the offset (Colin & Athanassoula 1989; Bournaud et al. 2005).

Although secular evolution may account for some of the observed properties of NGC922, we find that *all* the observed features of NGC922 can be explained by a high-speed, off-centre collision between a gas-rich spiral and a dwarf, which we model below. Since our main focus is on the observed properties of NGC922, rather than the details of the simulation results for a range of model parameters, we present only the results for which the observed morphology can be reproduced reasonably well. Detailed descriptions of the numerical methods and techniques used to model the dynamical evolution of interacting galaxies can be found in Bekki et al. (2002).

3.1 Model and simulations

NGC922 and S2 are represented by a self-consistent disk galaxy model and a point mass, respectively. The progenitor disk galaxy of NGC922 consists of a dark halo and a thin exponential disk. The masses and distances are measured in units of total disk mass ($M_{\rm d}$) and total disk size ($R_{\rm d}$). Velocity and time are measured in units of $v = (GM_{\rm d}/R_{\rm d})^{1/2}$ and $t_{\rm dyn} = (R_{\rm d}^3/GM_{\rm d})^{1/2}$, respectively. The units are scaled so that G = 1.0. The radial (R) and vertical (Z) density profiles of the disk are assumed to be proportional to $\exp(-R/R_0)$ with scale length R_0 = 0.2 and to $\mathrm{sech}^2(Z/Z_0)$ with scale length Z_0 = 0.04 in our units, respectively. The initial radial and azimuthal velocity dispersions are added to the disk component in accordance with epicyclic theory, and a Toomre parameter value of Q = 1.5 (Binney & Tremaine 1987).

The vertical velocity dispersion at a given radius is proportionally half the radial velocity dispersion such as observed in the Milky Way (e.g. Wielen 1977). Assuming that $M_{\rm d} = 2.0 \times 10^{10}$ $M_{\odot}$ and $R_{\rm d} = 13.4$ kpc for the disk galaxy; $v = 80.1$ km s^{-1}, $t_{\rm dyn} = 164$ Myr, radial scale length of the disk equals 2.68 kpc and the maximum rotational velocity equals 145 km s^{-1}. The total mass of NGC922 enclosed within $R_{\rm d}$ is 7.5×10^{10} $M_{\odot}$. The gas mass fraction of the spiral is assumed to be 0.2 and the Schmidt law (Schmidt 1959) with an index of 1.5 (Kennicutt 1989) is adopted for star formation in the disk galaxy.

The assumed mass ratio between the dwarf companion and the spiral is 0.2. $\mathbf{X}_{\rm g}$ and $\mathbf{V}_{\rm g}$ represents the initial locations and velocities of the companion with respect to the centre of the disk galaxy. For the model presented here: $\mathbf{X}_{\rm g} = (x, y, z) = (-4R_{\rm d}, 0.5R_{\rm d}, 0)$ and $\mathbf{V}_{\rm g} = (v_{\rm x}, v_{\rm y}, v_{\rm z}) = (6v, 0, 0)$. The inclination of the spiral with respect to the x-y plane is assumed to be 80 degrees, hence the $x - y$ plane roughly corresponds to the tangential plane of our images. The adopted values of $v_{\rm x} = 6v$ (corresponding to the relative velocity of $\sim$ 481 km s^{-1}) and $y = 0.5R_{\rm d}$ ($\sim$ 6.7 kpc) represents an off-centre very high speed collision. Note that stars that are initially within the spiral's disk are referred to as "stars" (or "old stars"), while, the stars that are formed after the collision from the gas are referred to as "new stars".

3.2 Results

Figure 3 describes how a ring galaxy is formed during an off-center collision between a spiral and its dwarf companion. The rapid passage of the companion through the disk initially causes the disk to contract as it feels the mass of the companion and then to expand as the mass disappears, resulting in an expanding density wave (Lynds & Toomre (1976); Hernquist & Weil (1993)). Within 0.2 Gyr of the spiral-dwarf collision, a non-axisymmetric ring-like structure and a tidal plume composed mainly of gas and old stars are formed. Owing to the strong compression of the disk gas, new stars have formed along the C-shaped ring.

In comparison to our observations, the observed morphology of NGC922 is best matched by the simulated model at 0.33 Gyr after the collision. At $T = 0.33$ Gyr, the radius of the ring is $\sim$ $14 - 15$ kpc and the distance between the simulated disk galaxy and its companion is $\sim$ 104 kpc. These values are comparable to both the observed radius of NGC922 and the projected distance between NGC922 and S2.

In Fig. 3, the companion is no longer visible at $T = 0.33$ Gyr due to its high relative velocity, while $v_{\rm z}(T = 0.33) \sim 203$ km s^{-1} of the intruder is in reasonable agreement with the radial velocity difference between NGC922 and S2. In conclusion, the observed ring morphology of NGC922 can be reproduced simply by passing a point mass through a disk galaxy as shown above.

4 CONCLUSIONS.

Block et al. (2001) showed that the structure of NGC922 determined from Fourier decomposition of IR images is similar to that of grand-design spirals, which are presumably evolving in a secular fashion. Hence the dominant galaxy may originally have been a spiral. However, concentrating on the IR properties minimises the significance of the star formation event which is well-traced by our Hα and UV observations. These show a very disturbed morphology. The most compelling argument for a drop through encounter in the NGC922 system is the ease in which this scenario can account for all the major features of the system: the off-centre star-forming

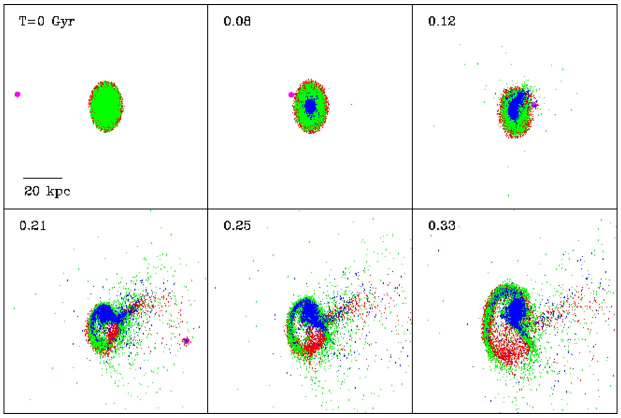

Figure 3. Morphological evolution of a gas-rich, bulge-less spiral colliding with a dwarf companion (represented by a big pink dot). Time (T) in Gyr since the start of the simulation is shown in the upper left corner of each panel. Stars, gas, and new stars are shown in green, red, and blue, respectively. For clarity, dark matter particles are not shown. The companion comes from the left side and passes through the central region of the spiral. Note that the simulated "C-shaped" morphology is strikingly similar to the observed morphological properties of NGC 922.

bar, a nearly complete star-forming ring, the low mass companion and the plume of stars apparently directed at the companion. We are not aware of any self-consistent secular models which also produce all these features.

Although ring or ring-like galaxies only account for 0.02-0.2% of all spiral galaxies (Athanassoula & Bosma 1985) in the local Universe, they should be more common at higher redshifts, since both galaxy density and the dispersion about the Hubble flow increase with redshift. C-shaped rings like that in NGC922 should be more common at all redshifts than complete rings like the Cartwheel galaxy, since off-axis collisions are more likely than on axis ones. Indeed, five out of the eight example high redshift *clump cluster* galaxies shown by Elmegreen et al. (2005) have a ring or partial ring morphology.

Our observations and simulations demonstrate that the ring galaxy NGC922 can be formed by the slightly off-axis passage of a dwarf companion through the disk of a spiral galaxy. A series of expanding density waves consisting of both stellar and gaseous material result from the collision and enhanced star formation in the ring and the core of NGC922 (due to the compression of the displaced gas) is observed. We are not able to discuss the star formation induced in the companion from these simulations since we simply modelled the companion as a point mass. In the future, more sophisticated simulations could probe the star formation scenario and stellar populations of the companion, while HI synthesis observations of the system could check for the existence of a gasseous tail between NGC922 and S2.

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REFERENCES

Athanassoula E., Bosma A., 1985, ARA&A, 23, 147
Bekki K., Forbes D. A., Beasley M. A., Couch W. J., 2002, MNRAS, 335, 1176
Bell E. F., McIntosh D. H., Katz N., Weinberg M. D., 2003, ApJS, 149, 289
Binney J., Tremaine S., 1987, Galactic dynamics. Princeton, NJ, Princeton University Press, 1987, 747 p.
Block D. L., Puerari I., Takamiya M., Abraham R., Stockton A., Robson I., Holland W., 2001, A&A, 371, 393
Bournaud F., Combes F., Jog C. J., Puerari I., 2005, A&A, 438, 507
Calzetti D., Armus L., Bohlin R. C., Kinney A. L., Koornneef J., Storchi-Bergmann T., 2000, ApJ, 533, 682
Calzetti D., Kinney A. L., Storchi-Bergmann T., 1994, ApJ, 429, 582
Colin J., Athanassoula E., 1989, A&A, 214, 99
Elmegreen D. M., Elmegreen B. G., Rubin D. S., Schaffer M. A., 2005, ApJ, 631, 85
Hernquist L., Weil M. L., 1993, MNRAS, 261, 804
Higdon J. L., 1996, ApJ, 467, 241
Jarrett T. H., Chester T., Cutri R., Schneider S., Skrutskie M., Huchra J. P., 2000, AJ, 119, 2498
Jones D. H., Saunders W., Colless M., Read M. A., Parker Q. A., Watson F. G., Campbell L. A., et al. 2004, MNRAS, 355, 747
Kennicutt R. C., 1989, ApJ, 344, 685
Kennicutt R. C., 1998, ARA&A, 36, 189
Kennicutt R. C., Tamblyn P., Congdon C. E., 1994, ApJ, 435, 22
Kewley L. J., Dopita M. A., 2002, ApJS, 142, 35
Koribalski B. S., Staveley-Smith L., Kilborn V. A., Ryder S. D., Kraan-Korteweg R. C., Ryan-Weber E. V., Ekers R. D., et al. 2004, AJ, 128, 16
Kormendy J., Kennicutt R. C., 2004, ARA&A, 42, 603
Lamareille F., Mouhcine M., Contini T., Lewis I., Maddox S., 2004, MNRAS, 350, 396
Lynds R., Toomre A., 1976, ApJ, 209, 382
Meurer G. R., Carignan C., Beaulieu S. F., Freeman K. C., 1996, AJ, 111, 1551
Meurer G. R., Hanish D., Ferguson H. C., Knezek P. M., Kilborn V. A., Putman M. E., Smith R. C., et al. 2006, submitted to ApJ
Meurer G. R., Heckman T. M., Calzetti D., 1999, ApJ, 521, 64
Meyer M. J., Zwaan M. A., Webster R. L., Staveley-Smith L., Ryan-Weber E., Drinkwater M. J., Barnes D. G., et al. 2004, MNRAS, 350, 1195
Mould J. R., Huchra J. P., Freedman W. L., Kennicutt R. C., Ferrarese L., Ford H. C., Gibson B. K., et al. 2000, ApJ, 529, 786
Schlegel D. J., Finkbeiner D. P., Davis M., 1998, ApJ, 500, 525
Schmidt M., 1959, ApJ, 129, 243
Seibert M., Martin D. C., Heckman T. M., Buat V., Hoopes C., Barlow T., Bianchi L., Byun Y.-I., et al. 2005, ApJ, 619, L55
Sparke L. S., Gallagher J. S., 2000, Galaxies in the universe : an introduction. Galaxies in the Universe, by Linda S. Sparke and John S. Gallagher, III, pp. 416. ISBN 0521592410. Cambridge, UK: Cambridge University Press, September 2000.
Wielen R., 1977, A&A, 60, 263

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